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We investigated symbolic aspects of commonsense reasoning. The formalisms studied — nonmonotonic logics — go beyond the classical logic and encompass such reasoning mechanisms as circumscription, default logic, autoepistemic logic, reason maintenance and logic programming with negation. The area of nonmonotonic logics is currently one of the most active topics in Artificial Intelligence and has potential applications in the next generation of Expert Systems and general reasoning software.

Main results of our research provide understanding of the dependence of nonmonotonic modal logics on the underlying monotonic modal logics, explain the relationships between most important modes of non-monotonic reasoning, provide algorithms for automated nonmonotonic reasoning as well as computational complexity results. Several pilot implementations of nonmonotonic reasoning engines were produced.

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Investigations of Logic of Introspection and Related Modes of Reasoning with Applications

Final Report

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Statement of the Problem Studied

Nonmonotonic logics attempt to formalize non-numerical aspects of commonsense reasoning. These logics go beyond the classical logic and encompass such formalisms as circumscription, default logic, autoepistemic logic, reason maintenance and logic programming with negation. The area of nonmonotonic logics is currently one of the most active topics in Artificial Intelligence and has potential applications in the next generation of Expert Systems and general reasoning software.

We studied modal nonmonotonic logics and their role in the area of nonmonotonic reasoning. Our research can roughly be categorized into four main topics.

1. Classification of types of reasoning in modal nonmonotonic logics;

2. Algorithms for modal nonmonotonic reasoning;

3. Complexity of nonmonotonic reasoning;

4. Relationship of modal nonmonotonic logics to other nonmonotonic systems such as default logic, logic programming and reason maintenance.

Summary of the Most Important Results

1. Dependence of nonmonotonic modal logics on the underlying monotonic

modal logics. We found that whole clusters of modal logics collapse to the same nonmonotonic modal logic. This unexpected result shows that nonmonotonic modal logics possess multiple semantics and proof systems. In addition, it follows that the class of modal nonmonotonic logics is much smaller than the class of the corresponding monotonic systems.

2. Algorithms for nonmonotonic reasoning. We designed methods for computing expansions, that is, sets of formulas accepted by a reasoning agent as a "belief sets".

3. Complexity of nonmonotonic reasoning. We determined the complexity of several modes of nonmonotonic reasoning such as autoepistemic reasoning, default reasoning and logic programming with stable semantics.

4. Understanding the relationship between various modes of nonmonotonic reasoning. Our research produced a large body of results including:

(a) a general theory of nonmonotonic rule systems;

(b) studies of modal nonmonotonic logic as a unified language for nonmonotonic reasonings;

(c) a number of technical results on default logic concerning normal forms for default theories;

(d) results in logic programming concerning complexity of stable semantics and limits of expressibility of locally stratified semantics.

5. Pilot implementations of nonmonotonic reasoning engines. This includes implementations of default logic and autoepistemic logic.

List of Publications

1. W. Marek, M. Truszczyński, Modal logic for defasult reasoning, Annals of Mathematics and Artificial Intelligence, 1(1990), 275 – 302.

2. W. Marek, A. Nerode and J.C. Remmel, Nonmonotonic Rule Systems I, Annals of Mathematics and Artificial Intelligence, 1990, Vol 1., 241–273.

3. M. Truszczyński, Modal nonmonotonic logic with restricted application of the negation as failure to prove rule, Fundamenta Informaticae, 14(1991), pp. 355-366.

4. M. Gelfond, V. Lifschitz, H. Przymusinska, M. Truszczyński, Disjunctive defaults, Proceedings of the Second International Conference on Principles of Knowledge Representation and Reasoning, KR '91, Morgan Kaufmann, 1991.

5. W. Marek, G. Schwarz, M. Truszczyński, Modal nonmonotonic logics: ranges, characterization, computation, extended abstract, Proceedings of the Second International Conference on Principles of Knowledge Representation and Reasoning, KR '91, Morgan Kaufmann, 1991.

6. W. Marek, G. Schwarz, M. Truszczyński, Ranges of strong modal nonmonotonic logics, *Proceedings of NIL'90*, Lecture Notes in Artificial Intelligence, Vol. 543, 1991, pp. 85 – 99. Springer Verlag.

7. W. Marek, M. Truszczyński, Computing the intersection of autoepistemic expansions, *Proceedings of the First International Workshop on Logic Programming and Non-monotonic reasoning*, Washington, DC, 1991, MIT Press.

8. M. Truszczyński, Modal interpretations of default logic, Proceedings of IJCAI-91, pp. 393 – 398.Morgan Kaufmann, 1991;

9. M. Truszczyński, Embedding default logic into modal nonmonotonic logics, *Proceedings of the First International Workshop on Logic Programming and Non-monotonic reasoning*, Washington, DC, 1991, MIT Press.

10. W. Marek, G. Schwarz, M. Truszczyński, Modal nonmonotonic logics: ranges, characterization, computation, accepted for publication in the Journal of the ACM.

11. W. Marek, A. Nerode and J.C. Remmel, How complex is the set of models of a logic program, accepted for publication in Annals of Pure and Applied Logic.

12. M. Fiting W. Marek, M. Truszczyński, Logic of necessitation, accepted for publication in Journal of Logic and Computation.

13. G. Schwarz, M. Truszczyński, Modal Logic S4F and the minimal knowledge paradigm, Proceedings of TARK-IV, Morgan Kaufmann, 1992.

14. W. Marek, A. Nerode and J.C. Remmel, Nonmonotonic Rule Systems II, accepted for publication in Annals of Mathematics and Artificial Intelligence.

List of Presentations

1. W. Marek: Classifications of expansions, International Symposium on Artificial Intelligence and Mathematics, Ft. Lauderdale, Jan. 1990 (invited talk).

2. M. Truszczynski: Modal logic for default reasoniog, International Symposium on Artificial Intelligence and Mathematics, Ft. Lauderdale, Jan. 1990 (invited talk).

3. W. Marek: Theory of Nonmonotonic Rule Systems, 2nd International Workshop on Metaprogramming Leuven, Belgium, April 1990.

4. M. Truszczynski: Kernels of Directed Graphs and Reasonings with Incomplete Information, Third Cumberland Conference on Graph Theory and Applications to Computer Science, Louisville, May, 1990.

5. W. Marek: Theory of Nonmonotonic Rule Systems, Logic in Computer Science (LICS) International Conference, Philadelphia, PA, June 1990.

6. M. Truszczynski, Modal nonmonotonic logics with restricted application of "negation as failure to prove" rule, Workshop on Logic Programming and Non-Monotonic Reasoning at North American Conference on Logic Programming, Austin, TX, Nov. 1990.

7. W. Marek, Stable models of programs and hierarchy of subsets of function spaces, Workshop on Logic Programming and Non-Monotonic Reasoning at North American Conference on Logic Programming, Austin, TX, Nov. 1990.

8. W. Marek, Modal nonmonotonic logics, Workshop on Non-Monotonic and Inductive Logics, Karlsruhe, Germany, December 1990.

9. M. Truszczyński, Modal nonmonotonic logics; ranges, characterizations, computation, Second International Conference on Knowledge Representation, KR'91, Cambridge, MA, April, 1991.

10. W. Marek, Computing intersection of autoepistemic expansions, First International Workshop on Logic Programming and Non-monotonic Reasoning, Washington, DC, July 1991.

11. M.Truszczyński, Embedding default logic into modal nonmonotonic logics, First International Workshop on Logic Programming and Non-monotonic Reasoning, Washington, DC, July 1991.

12. M. Truszczyński, Modal interpretations of default logic, IJCAI-91, Sydney, Australia, August 1991.

13. W. Marek, Modal logic and logic programs, Workshop on Nonmonotonic and Inductive Logic, Rheinsbrunns Castle, Germany, December 1991.

Cooperation with the Army Personnel

1. Dr. W. Marek visited Army Research Office in January 1991 and gave a presentation of the current research.

2. Dr. W. Marek visited Ballistic Research Laboratory in March 1991, consulted with Dr. P. Broome and gave a lecture on the applications of our research.

3. Dr. P. Broome of Ballistic Research Laboratory visited the University of Kentucky in May, 1991 and gave a presentation.

4. Dr. W. Marek visited several times Army Mathematical Sciences Institute at Cornell University, consulted with Dr. A. Nerode and attended the Army-sponsored meeting "Hybrid Systems".

Scientific Personnel Involved in the Project

1. Dr. Victor W. Marek, Department of Computer Science, University of Kentucky.

2. Dr. Mirosław Truszczyński, Department of Computer Science, University of Kentucky.

3. Mr. Nayan Shah, Research Assistant, obtained M.Sc., 1991.

4. Mr. Manish S. Vadyia, Research Assistant, obtained M.Sc., 1991.

5. Ms. Ching Yang, Research Assistant, obtained M.Sc., 1991.

6. Mr. Paweł Cholewiński, Research Assistant, Ph.D. program, current.

7. Mr. Artur Mikitiuk, Research Assistant, Ph.D. program, current.

8. Mr. Radek Vingralek, Research Assistant, Ph.D. program, current.